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Insect attraction to wind turbines: does colour play a role?

C. V. Long · J. A. Flint · P. A. Lepper

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Abstract The phenomenon of wildlife mortality at wind turbine installations has been generating increasing concern, both for the continued development of the wind industry and for local ecology. While an increase in aerial insectivore activity in the vicinity resulting from insect attraction to turbines remains a strong possibility, little research exists on the possible causes for such events. In this paper, the relative attraction of a selection of specific turbine colours and other hues is assessed in order to determine if turbine paint colour could be influencing insect numbers at these installations. The common turbine colours ‘pure white’ (RAL 9010) and ‘light grey’ (RAL 7035) were among those found to attract significantly more insects than other colours tested, suggesting colour may well have a role to play in potential mitigation.

Keywords Wind power · Wildlife mortality · Insects · Colour · Turbines

Introduction

In recent years, concern has been growing over the phenomenon of avian and bat mortality at wind turbine installations, an issue that could potentially be an obstacle to the growth of the wind industry sector, particularly at sites known to be inhabited by rare or protected species. While both insectivorous birds and bats are involved with turbine mortality, in some cases the number of bat carcasses

retrieved considerably outnumbers those of birds (e.g. Kerns and Kerlinger 2004; Piorkowski 2006). Whilst it is still unclear why bats frequent wind turbine installations, recent research has shown that bats appear to actively investigate turbine rotors (Horn et al. 2008). Some species may be assessing them as potential roost sites (Cryan 2008), however there is also some evidence of foraging behaviour around turbines (Horn et al. 2008; Ahlén 2004). Bats tend to be concentrated in areas of high insect density (Nicholls and Racey 2007) and are much more likely to begin hunting when large numbers of insects are congregating (Griffin et al. 1960). Reports into bat–turbine interactions frequently state the importance of investigation into the possibility of insect attraction to turbines (e.g. Johnson and Kunz 2004; Ahlén 2004; Nicholls and Racey 2007; Rodrigues et al. 2006), particularly since the recent loss of feeding habitats may be pressuring bats to feed in alternative areas (Wickramasinghe et al. 2003). Turbine colour may play an important part in insect attraction (Ahlén 2004), although to date this has not been closely investigated. Turbines are mostly painted white (Johnson and Kunz 2004) or shades thereof; the reasoning behind painting turbines in light colours appears to be connected with making turbines ‘visually unobtrusive’ against the skyline, to make them ‘blend well into the landscape’, or to make them easier to locate for meteorological purposes (Danish Wind Industry Association DWIA 2003). In the case of offshore turbines, light colours minimize visibility from shore (Department of Trade and Industry (DTI) 2005). Offshore turbines are also required to be painted yellow from the level of ‘highest astronomical tide’ up to 15 m (Department of Trade and Industry DTI 2005) to ensure they are visible to ships. Turbines are typically coloured by paint mixed to RAL colour specifications; RAL is an established firm which has been producing colour standards

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for more than 70 years. The two most common turbine paint shades are ‘Pure White’ (RAL 9010) or ‘Light Grey’ (RAL 7035) (e.g. Vestas Wind Systems 2006). Turbine colour is usually dependent on local building regulations and occasionally turbines are painted in other shades, for example ‘Squirrel Grey’ (RAL 7000) (Bracknell Forest Borough Council 2007), a colour which was chosen as it was deemed to ‘blend in better with a rural landscape and the UK skyline’, and was ‘less visually obtrusive’ than green, brown or black (Bracknell Forest Borough Council 2007). The effect of the colour selection on bird and bat mortality was not stated to have been considered in this case. To date, there has been one notable study to investigate effects of turbine colour, by Young et al. (2000), with regard to painting turbines with ultraviolet (UV) reflective paint as a visual warning for birds. The results indicated an increase in the number of avian fatalities around UV painted turbines (68% at UV turbines; 15% at non-UV turbines). It could be speculated that the UV paint would increase the attraction of insects to the turbine, and thus the attraction of insectivorous birds; this theory is supported by the fact that the vision of many insects is shifted towards the UV portion of the spectrum (Briscoe and Chittka 2001) (e.g. members of the fly genus *Drosophila* are consistently attracted to UV reflecting objects, a trait frequently exploited by web-making spiders (Craig and Bernard 1990)). In this study, the insect attraction to specific turbine colours is systematically investigated in order to identify whether this might need to be considered for future wildlife–turbine mitigation.

Methods

Study area

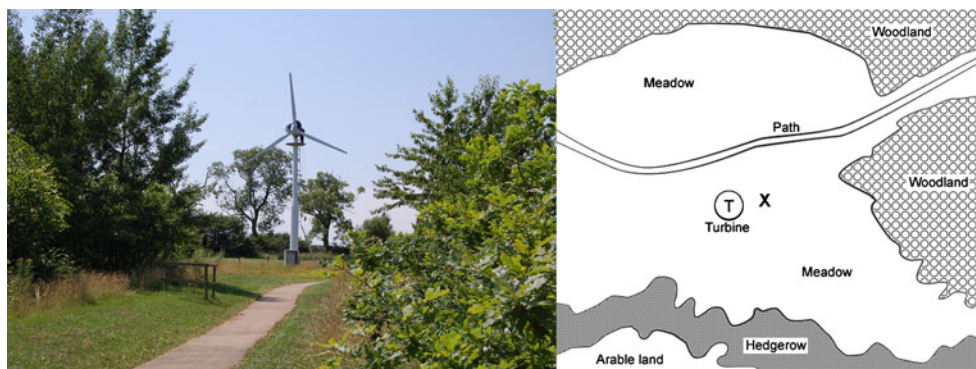
The location for experimental work was a meadow at the base of a 13-m, three-blade turbine (light grey), approximately 5 m from the base. This turbine was situated in an area of public parkland, at GPS coordinates 52°35′16.70″N, 1°05′06.28″W in Oadby, Leicestershire, UK. Deciduous

woodland and hedgerow (see Fig. 1) surrounded the meadow on all sides; there was an abundance of local bird and bat activity (although no documented mortality incidents) in the vicinity.

Data collection

A selection of ten reference colour cards from the RAL colour range were used, each measuring 215 by 303 mm and impregnated on one side with the specified RAL colour by the manufacturer (RAL gemeinnützige GmbH, Germany). The colours chosen were as follows; RAL 9010 ‘Pure White’ (white), RAL 7035 ‘Light Grey’ (light grey), RAL 7000 ‘Squirrel Grey’ (dark grey), RAL 5015 ‘Sky Blue’ (blue), RAL 3020 ‘Traffic Red’ (red), RAL 4001 ‘Red Lilac’ (purple), RAL 1023 ‘Traffic Yellow’ (yellow), RAL 8025 ‘Pale Brown’ (brown), RAL 6026 ‘Opal Green’ (green) and RAL 9005 ‘Jet Black’ (black). Colours were selected in such a way as to produce a varied spectrum of samples, in addition to the common turbine colours (white and light grey), a less common turbine colour (dark grey), and black. Some of the other additional colours were chosen for various reasons; several flower visiting insects express an innate colour preference (Lunau and Maier 1995) with many insects being attracted to yellow colours (560–590 nm) (Prokopy and Owens 1983), including Diptera (flies) and Lepidoptera (butterflies and moths) (Kevan 1983). Blue flowers (400–500 nm) have been observed to be particularly attractive to Hymenoptera (bees) (Kevan 1983), while pink and red flowers (650–700 nm) are frequently visited by Lepidoptera (Kevan 1983). In order to protect colour cards and to prevent discolouration by moisture contamination and other debris, each card was laminated inside a transparent plastic pocket. An empty laminated pocket was included in the study as a transparent control. To assess the relative ‘attractiveness’ of each colour card to insects, cards were laid out, face up, in two rows of six and five cards, respectively, approximately 2 cm apart. Each card was then observed, in turn, for a set period of time, during which the number of flying insects present on or within approximately 10 cm from the card’s

Fig. 1 Local habitat of the study site: a photograph of the site (*left*) taken in July at mid-day, and an aerial plan diagram of the immediate area (*right*), where ‘X’ denotes the precise location of measurements



surface was recorded. After 5 s, the next card along the grid was observed, and so on in an anti-clockwise pattern, over a total of 10 min. By assessing cards in this manner, it is quite possible to re-count the same insect on the same card several times; this is not problematic as it effectively weights the count to account for a greater attraction to any one colour card. After this 10-min period, the cards were gathered, carefully cleaned, shuffled and randomly re-distributed throughout the grid in order to avoid potential bias caused by the proximity of any one colour to another. This was repeated three to five times in succession and the insect species present noted at the end. For sunset observations only, a low power torch (300 lx peak luminous emittance at 300 mm) was used to illuminate the card under observation in order to facilitate insect identification. While certain nocturnal insect species, such as moths, are known to be attracted to light sources, the torch was used consistently for observations and turned off between readings in order to minimise any bias caused by its use. Each set of measurements were taken between the months of June to October, corresponding with the months of peak bat activity, over a 3-year period. In year 1, readings were taken at midday only, in year 2, readings were taken 1 h after sunset only, and in year 3, readings were taken both at midday and 1 h after sunset on the same day. Before each measurement, the time and weather conditions were noted and temperature, relative humidity (RH) and wind speed readings taken from an HHF81 digital 4-in-1 meter (OMEGA Engineering, Inc., Stamford, CT, USA). In addition, the wavelength spectral reflectance peaks (within a range of 900–300 nm) of all cards used in the experiment were measured using a UV/VIS Lambda Bio 40 Spectrometer (Perkin-Elmer, Inc., Waltham, MA, US).

Statistical analysis

Data were analysed using the GLM ANCOVA module of Statistica 5.1 (StatSoft, Inc., Tulsa, OK, USA). ‘Insect count per 10 min period’ was selected as the dependent variable in all cases, while either ‘colour’, ‘month’, ‘time of day’, ‘year’, ‘weather conditions’, ‘temperature’, ‘relative humidity’ or ‘wind speed’ were chosen as independent variables. Since these factors also varied in conjunction with the independent variables, in all cases the relevant variables from ‘colour’, ‘month’, ‘time of day’, ‘year’, ‘weather conditions’, ‘temperature’, ‘relative humidity’ and ‘wind speed’ were selected as covariates. In order to assess the importance of spectral peak percentage reflection, peak UV reflection and peak infrared (IR) reflection, these were selected as independent variables with ‘insect count per 10 min period’ as dependent variable and ‘colour’, ‘month’, ‘year’, ‘weather conditions’, ‘temperature’, ‘relative humidity’ and ‘wind speed’ selected as covariates. Because UV

and IR measurements taken represented reflection in peak light conditions, this analysis was applied only to midday measurements with weather conditions of ‘sunny’ and ‘sunny spells’.

Results

A total of 2012 insect observations were made over the 3-year course of the study, from fifty-nine 10-min sessions. Note that approximately 90% of insects counted had landed on the surface of the colour cards.

Effects of colour on insect attraction

Colour was found to have an overall significant effect on insect count ($p < 0.0005$; $F_{[10,631]} = 3.25$); Fig. 2 demonstrates the total mean insect count for each colour tested. Of these colours, yellow was the most attractive overall ($p < 0.00005$; $F_{[2,631]} = 11.09$); however, the turbine colours white and light grey were significantly more attractive than all other colours (excluding yellow) tested ($p < 0.05$; $F_{[2,631]} = 4.34$). Purple attracted significantly fewer insects overall ($p < 0.05$; $F_{[2,631]} = 4.63$) than any of the other colours tested.

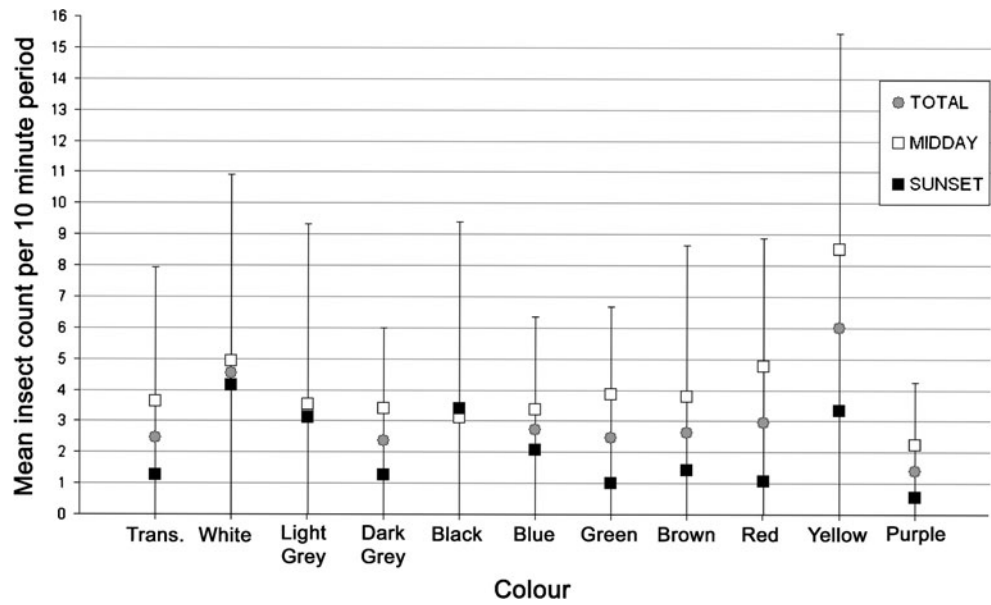
Effects of spectral reflectance on insect count

Spectral reflectance peaks were found to vary between each colour card tested, both in the visible, UV and IR spectrum (Fig. 3). Overall, peak spectral reflectance had a significant effect on insect count per 10 min period ($p < 0.005$; $F_{[9,225]} = 3.0$) for midday (sunny and sunny spells) measurements. Both peak UV reflectance and peak IR reflectance significantly influenced insect count ($p < 0.005$; $F_{[9,225]} = 3.0$; $p < 0.05$; $F_{[8,226]} = 2.82$) with higher spectral reflectance in these ranges attracting more insects. The card colours yellow and white gave the highest IR reflectance peak, while the transparent ‘control’ card, interestingly, gave the highest UV peak (see Fig. 3).

Seasonal, annual and meteorological effects on insect count

Time of day was found to significantly influence insect numbers; total insect counts were significantly lower after sunset than at midday ($p < 0.00005$; $F_{[1,640]} = 18.44$), although this phenomenon did vary according to colour (see Fig. 2). Insect counts varied significantly according to month ($p < 0.00005$; $F_{[4,637]} = 10.76$) over the course of the data collection period. The month of July had the highest total mean count and October the lowest, as shown in Fig. 4. Relative insect attraction to each colour was found not to be consistent between months or times of day, as demonstrated in Fig. 5. Table 1 describes the insect orders

Fig. 2 Mean insect count per 10-min period for each colour tested. Grey circles indicate total means with \pm standard deviation whiskers; white and black boxes indicate means for midday and sunset +1 h counts, respectively



observed each month during the data collection period. Weather conditions had an overall significant effect on insect count ($p < 0.005$; $F_{[4,637]} = 3.82$) with fewer insects observed in ‘clear’ and ‘cloudy’ weather than other conditions (‘overcast’, ‘sunny spells’, ‘sunny’). Figure 6 demonstrates the effect of wind speed, temperature and RH on total mean insect counts per 10 min period; temperature significantly influenced insect count ($p < 0.00005$; $F_{[10,631]} = 8.31$) with the highest activity observed at 15°C and 16°C. RH also significantly influenced insect activity ($p < 0.05$; $F_{[3,638]} = 2.93$) with lowest activity at 60–69% RH, as did wind speed ($p < 0.00005$; $F_{[5,636]} = 1.75$) with speeds of 2.5–4.4 ms^{-1} showing the highest counts.

Discussion

The finding that the common turbine colours white and light grey were amongst the most attractive colours to insects, independent of time of day, is of significant importance. Insects attracted to a turbine mast and rotor present a foraging opportunity to local insectivores, and thus this is likely to greatly increase the time spent in the vicinity of the turbine, which in turn increases the risk of fatal interaction with operational rotors. Furthermore, it is conceivable that flying insects attracted to white turbine structures could then become trapped in the rotor wake vortices (Arnett et al. 2008; Johnson and Kunz 2004). It is

Fig. 3 Spectral reflectance data for each experimental card, demonstrating peaks in reflectance for wavelengths between 900 (infrared) to 300 (ultraviolet) nm. Note that the reflectance peak for the transparent card is more than 100% due to fluorescence in the UV range

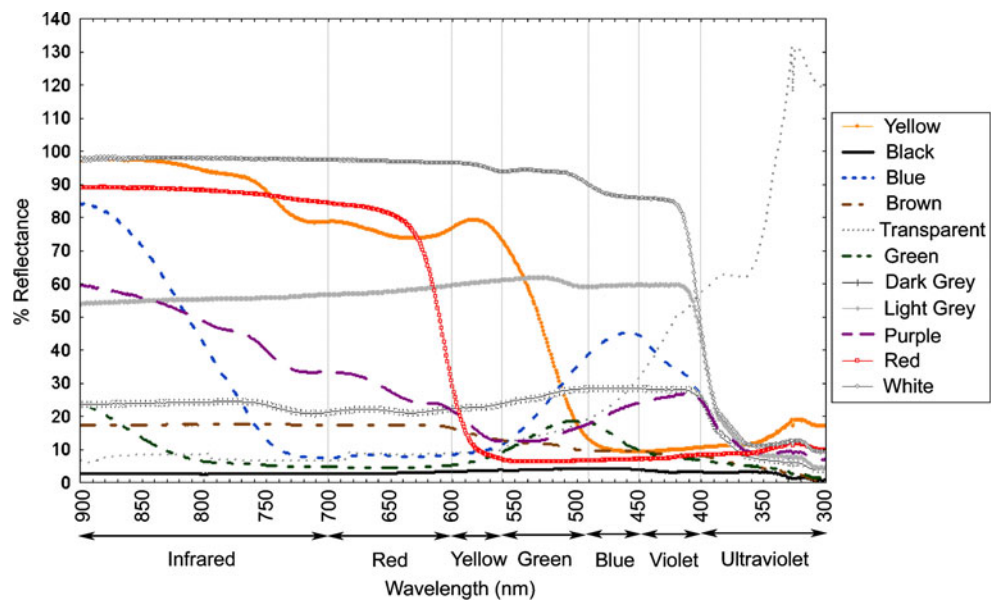
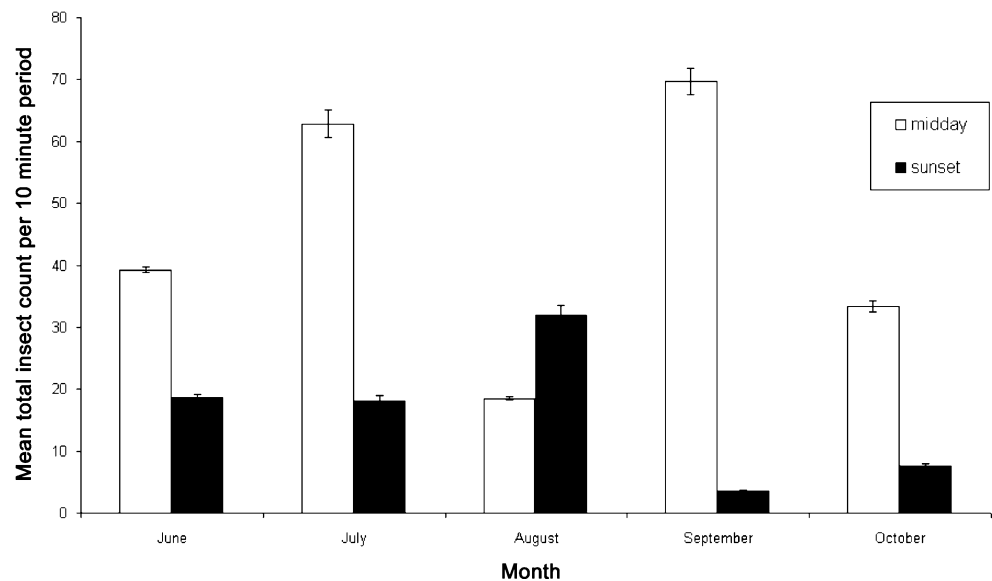


Fig. 4 Mean total insect count per 10 min period according to month of observation, at both midday and 1 h after sunset



not entirely clear why these light white and near-white colours are attractive to insects; Prokopy and Owens (1983) noted that foliar reflectance occurs about 350–650 nm, which accompanied by a lower saturation via an increase in UV and blue reflectance results in a ‘whitish’ appearance. It could therefore be that insects mistake the white colour of the turbine for foliage and are drawn to it for foraging, mating or resting opportunities. White flowers have also been found to be highly visually attractive to a wide range of insects (Kevan 1983). It therefore appears important to consider alternative turbine colours for future installations, particularly in areas known to be high in insectivore activity. Whilst white and light grey are by far the most common choices for turbine colour, dark grey is also known to be used; dark grey appeared to be slightly less attractive overall than light grey (Fig. 2), although this trend was not significant ($F_{[2,631]}=1.73$).

Several other colours had marked effects on overall relative insect attraction. The fact that one colour demonstrated the lowest overall insect count (purple) indicates there are also likely to be other suitable candidates for turbine colour that are not highly attractive to insects independent of season, and these need to be further investigated for mitigation purposes. Whilst the high attractiveness of the colour yellow found in the experiment agreed with expectations (given the link between the yellow colour of many pollen types at the centre of flowers where nectar is located, and the spectral peak at which green leaves reflect most light (Prokopy and Boller 1971)), the high insect counts for the colour black were somewhat surprising. It may be speculated that the heat-absorbing properties of this colour acted as a ‘thermal lure’ for some insects observed. Black attracted more insects in the colder months of September and October during midday observations (Fig. 5), and was also the only colour to attract more

insects, on average, after sunset than at midday (Fig. 2). Many insects are influenced by thermal gradients; tabanid flies, for example, have an exceptionally strong attraction to heat (Thorsteinson 1958), and so it is important to consider the thermal properties of the turbine structure in addition to colour. Both Ahlén (2004) and Horn et al. (2008) have used thermal imaging cameras on operational turbines to investigate this effect, finding the top portion of the tower, the blades and nacelle to appear warmer than the surrounding air. Insects may be attracted to the warmer air around the nacelle, particularly in autumn (Dürr and Bach 2004), which requires further investigation in conjunction with colour effects.

The transparent ‘control’ was found not to differ significantly in attractiveness as compared to all other colours ($F_{[2,631]}=1.69$), which may have been due to the reflection of UV light from the card during midday readings. The results of the spectral reflectance tests (Fig. 3) confirm that this card reflected strongly in the UV region under peak light conditions, even fluorescing above 100% reflectance. This theory is supported by the higher midday insect counts for June and July (Fig. 5), months more likely to experience weather conditions of ‘sunny’ or ‘sunny spells’ in the dataset and UV index is highest.

It is interesting to note that the UV reflectance of the colour cards was markedly reduced as compared to the transparent laminate, despite all cards being laminated inside identical plastic pockets. This suggested that the coloured paints have UV absorbing properties, although the extent to which UV is absorbed did vary between colours. Because paint colours reflecting more UV light attracted significantly more insects under strong light conditions (even when the transparent card was not included in analysis ($p<0.05$; $F_{[8,573]}=2.66$)), it may be important to select paint colours which do not have strong UV

Fig. 5 Variation in mean insect count for each colour per 10 min period according to month, for both midday (a) and 1 h after sunset (b) observations

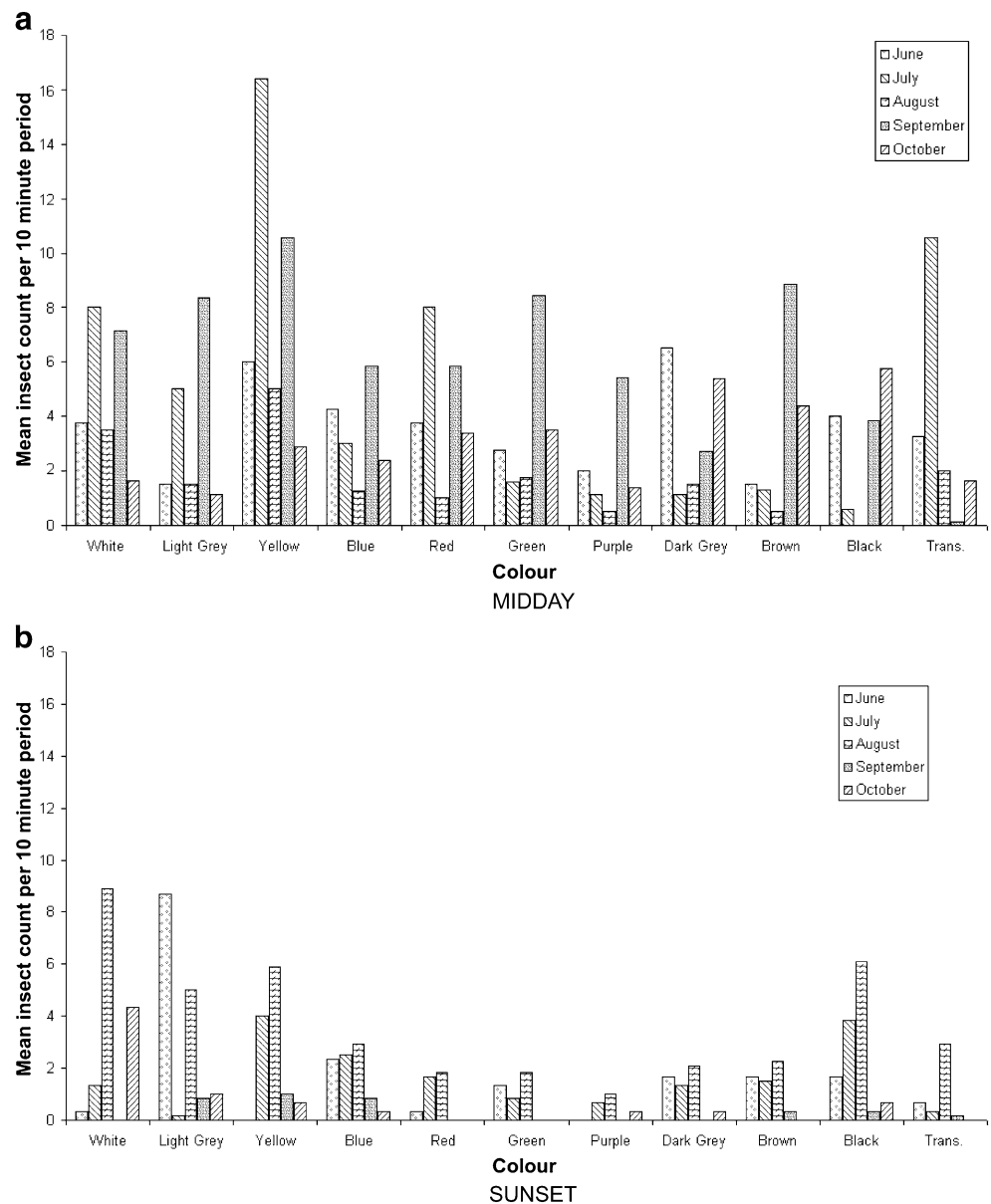
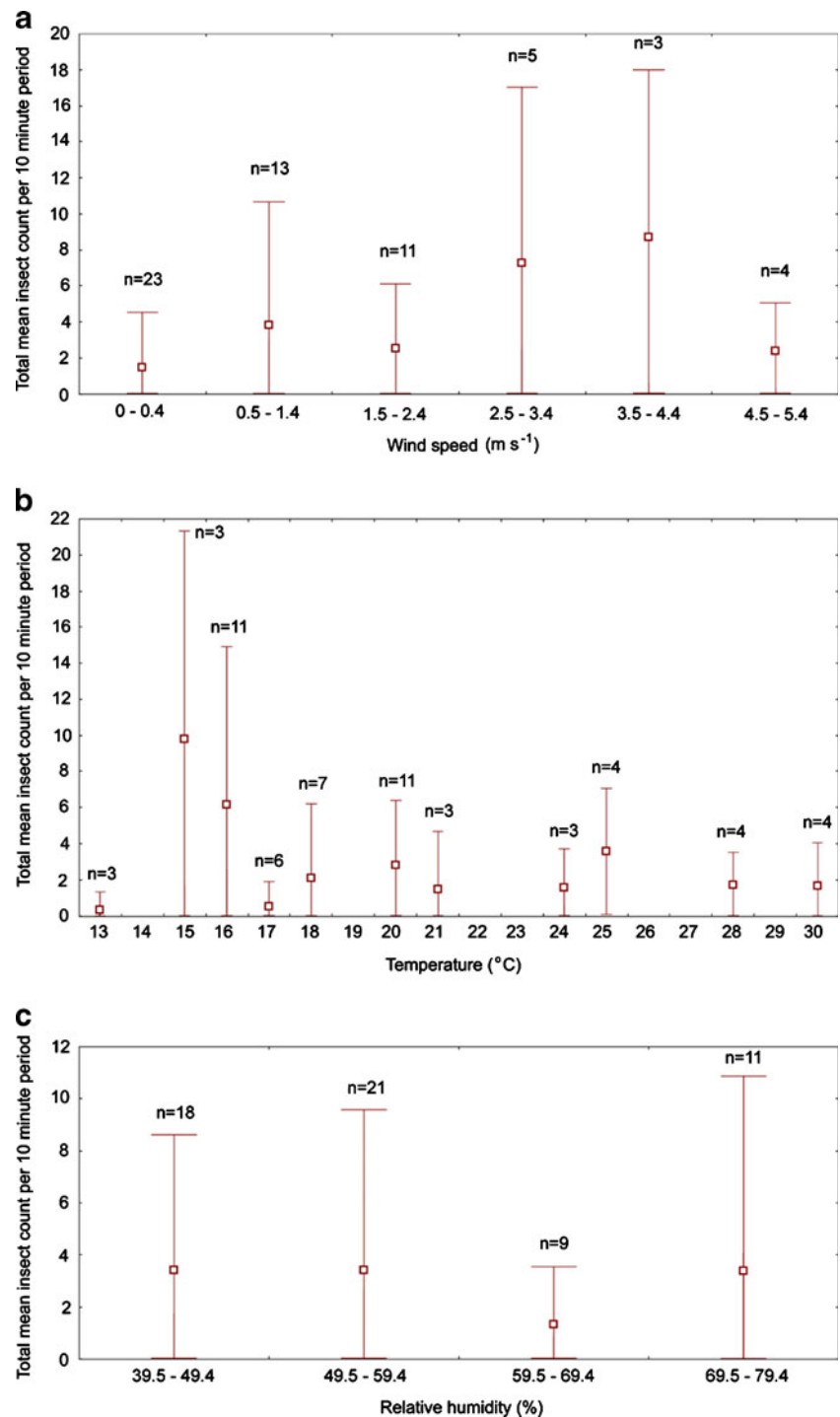


Table 1 Insect species observed over the data collection period

Month	Insect species (midday)	Insect species (sunset)
June	Small Diptera (body size <5 mm), large Diptera (body size \geq 5 mm), Hemiptera, Orthoptera	Orthoptera, Hemiptera, Coleoptera
July	Small Diptera (<5 mm), large Diptera (\geq 5 mm), Thysanoptera, Coleoptera, Lepidoptera, Hymenoptera, Hemiptera, Orthoptera	Small Diptera (<5 mm), Hemiptera
August	Small Diptera (<5 mm), large Diptera (\geq 5 mm), Thysanoptera, Lepidoptera, Hymenoptera, Hemiptera	Small Diptera (<5 mm), large Diptera (\geq 5 mm), Coleoptera, Lepidoptera, Thysanoptera, Hemiptera, Tipulidae
September	Small Diptera (<5 mm), large Diptera (\geq 5 mm), Tipulidae, Thysanoptera, Hemiptera, Hymenoptera, Coleoptera	Small Diptera (<5 mm), large Diptera (\geq 5 mm), Hemiptera, Thysanoptera, Coleoptera, Tipulidae
October	Small Diptera (<5 mm), large Diptera (\geq 5 mm), Hemiptera	Small Diptera (<5 mm), large Diptera (\geq 5 mm), Hemiptera, Coleoptera

Fig. 6 Effect of environmental conditions on total mean insect count per 10 min period, including wind speed (a), temperature (b) and relative humidity (c). Boxes indicate means with \pm standard deviation whiskers. In all cases n represents the number of 10-min sessions performed at that range



reflectance peaks for turbine installations. Similarly, the fact that paint colours with strong IR reflectance attracted significantly more insects (the turbine paint colour white had an IR peak identical with that of yellow; Fig. 3) indicates IR reflective properties may need to be taken into consideration in addition to visible colour spectrum alone. As the least attractive colour, purple, had a UV reflectance

of 10% and an IR reflectance of 60%, this could provide a useful comparison for turbine paint colour selection in relation to insect attraction under strong light conditions.

Seasonal variation in the relative attraction of insects to specific colours (as shown in Fig. 5) could be affected by the seasonality of the different insect species observed (see Table 1). For example, while small and large Diptera,

common prey items for insectivorous wildlife, were present throughout all monthly midday counts and most sunset counts, species belonging to the order Tipulidae were present only in August and September. The variation in attraction of different colours between different insect species was not a factor that was considered in this study, but may account for some degree of seasonal variation. Monthly variation is also likely to be linked with changes in temperature, weather conditions and RH which all have significant interplay with insect activity levels (e.g. Willmer 1983; McCall and Primack 1992), which our own data support. It is particularly interesting to note the relationship between total insect count and wind speed, with low 3–4 m s⁻¹ speeds showing the highest activity levels. Previous studies have identified that bat mortality in particular is highest on low wind speed nights (less than 6 m s⁻¹) (Arnett et al. 2008; Horn et al. 2008) which could well be correlated with improved foraging opportunities at these lower wind speeds.

It is suggested that future studies investigate the effects of moving colours such as colour cards and painted blades/turbines on insect attraction. A logical next step would be to paint turbines at known sites of wildlife interaction and investigate frequency of interaction between turbines and insectivores.

In conclusion, our results indicate that the common turbine colours 'Pure White' (RAL 9010) and 'Light Grey' (RAL 7035) may be having a significant influence on the attraction of insects to wind turbine installations, which could in turn be providing foraging opportunities for both diurnal and nocturnal insectivores. Because some colours were demonstrated to be less attractive to insects than others it may therefore be possible to contribute to reducing insect attraction to wind turbines by altering paint colours, both in the visible spectrum and in the UV and IR spectrum. However, it should be made clear that modifying turbine colour alone may not be enough to mitigate the problem of wildlife–turbine interaction and that further research into other aspects such as thermal generation is needed.

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